Multiphase Flow Modelling within FLUIDITY

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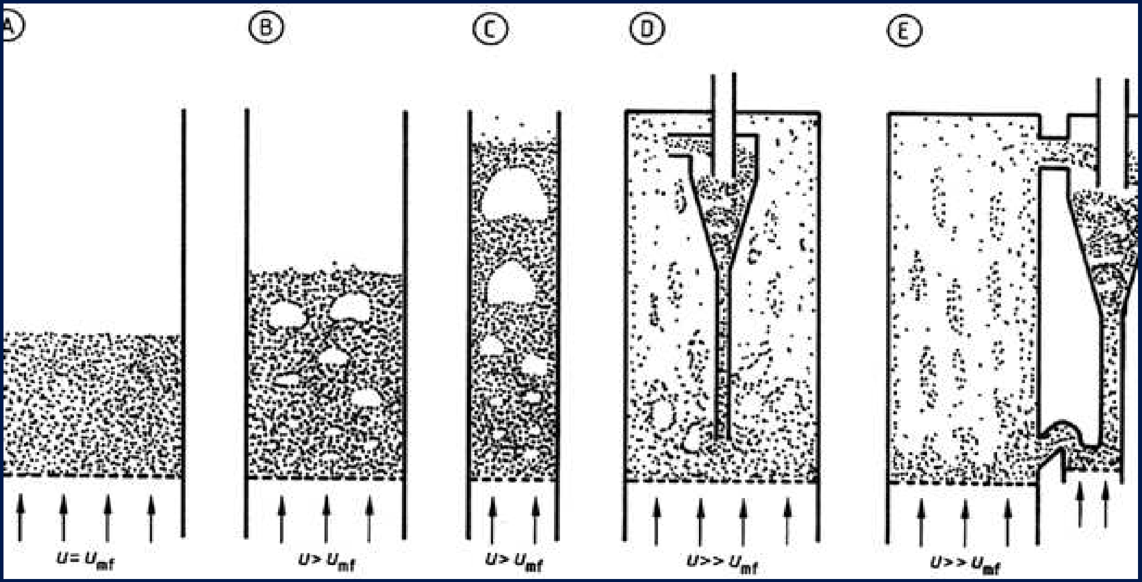
Summary

- Multiphase, Multifluid and Multicomponent
- The Two-Fluid Granular Temperature Model (TFGTM)
- Conservative and Constitutive Equations
- FETCH
- Some Applications

Multiphase, Multifluid and Multicomponent

- Differences
- Dense and dilute flows
- Definitions: fluidisation regimes



A
B
C
D
E
$U = U_{mf}$
$U > U_{mf}$
$U > U_{mf}$
$U >> U_{mf}$
$U >> U_{mf}$

The Two-Fluid Granular Temperature Model (TFGTM)

Both phases are described as interpenetrating continua and corresponding mass, momentum, thermal energy and fluctuation energy balance equations are solved with interaction terms representing the coupling between the phases.

$$\frac{\partial}{\partial t}\left(\varepsilon_k \rho_k\right) + \frac{\partial}{\partial x_i}\left(\varepsilon_k \rho_k v_{ki}\right) = 0 \tag{1}$$

$$\frac{\partial}{\partial t}\left(\varepsilon_k \rho_k v_{ki}\right) + \frac{\partial}{\partial x_j}\left(\varepsilon_k \rho_k v_{ki} v_{kj}\right) = -\varepsilon_k \frac{\partial p_g}{\partial x_i} + \tag{2}$$

$$\varepsilon_k \rho_k g_i + \beta\left(v_{k'i} - v_{ki}\right) - \frac{\partial}{\partial x_i}\left(\tau_{kij}\right) - \Gamma_k v_{ki}$$

- Fluidisation model A and B (pressure gradient term)
- Third & forth terms: interaction force representing the momentum transfer between the fluid and solid phases and the stress tensor, respectively.
- Fifth term: frictional force exerted by the phase k on the wall

Conservative Equations

$$\frac{3}{2}\left[\frac{\partial}{\partial t}\left(\varepsilon_s\rho_s\Theta\right)+\frac{\partial}{\partial x_j}\left(\varepsilon_s\rho_s v_{s_j}\Theta\right)\right]=\tau_{s_{ij}}\frac{\partial v_{s_i}}{\partial x_j}-\frac{\partial q_j}{\partial x_j}-\gamma-3\beta\Theta \tag{3}$$

- The last terms of Eqn. 3 represent the diffusive flux of granular energy, rate of granular energy dissipations due to inelastic collisions and the transfer of granular energy between the fluid and solid phases

$$\begin{aligned}\frac{\partial}{\partial t}\left(C_f\varepsilon_f\rho_f T_f\right)=-p_f\left[\frac{\partial}{\partial x_i}\left(\varepsilon_f v_{fi}\right)+\frac{\partial}{\partial x_i}\left(\varepsilon_s v_{si}\right)\right]+\\ \frac{\partial}{\partial x_i}\left(\varepsilon_f\kappa_f\frac{\partial T_f}{\partial x_i}\right)+\alpha\left(T_s-T_f\right)+\Omega_{wf}\end{aligned} \tag{4}$$

$$\frac{\partial}{\partial t}\left(C_s\varepsilon_s\rho_s T_s\right)=\frac{\partial}{\partial x_i}\left(\varepsilon_s\kappa_s\frac{\partial T_s}{\partial x_i}\right)+\alpha\left(T_f-T_s\right)+\Omega_{ws}+\mathcal{S}_f \tag{5}$$

Conservative Equations - Summary of the Multicomponent Submodel

$$\frac{\partial \hat{\varepsilon}_{sh}}{\partial t} + \nabla \cdot v_s \hat{\varepsilon}_{sh} = 0 \quad \forall h \in \{1, n\} \tag{6}$$

where $\hat{\varepsilon}_{sh}$ is the normalized concentration of powder h. Therefore, Eqn. 1 may be rewritten for the solid phase as

$$\frac{\partial}{\partial t}\left(\rho_{sh}\varepsilon_{sh}\right) + \nabla \cdot \left(\varepsilon_{sh}\rho_{sh}v_s\right) = 0 \quad \forall h \in \{1, n\} \tag{7}$$

$$\begin{aligned} C_f \rho_f \epsilon_f \frac{DT_f}{Dt} = -p_f \left(\frac{\partial}{\partial x_i}\varepsilon_f v_{g_i} + \frac{\partial}{\partial x_i}\varepsilon_s v_{s_i}\right) + \\ \frac{\partial}{\partial x_i}\left(\varepsilon_f \kappa_f \frac{\partial T_f}{\partial x_i}\right) + \alpha\left(T_s - T_f\right) + \widehat{\Gamma}_{wf}, \end{aligned} \tag{8}$$

$$\sum_{h=1}^{n} \frac{\partial}{\partial t} \left(C_{sh} \rho_{sh} \varepsilon_{sh} T_s \right) = \sum_{h=1}^{n} L_{c,h} \varepsilon_{sh} \frac{\partial G_h^{k,k'}}{\partial t} + \sum_{h=1}^{n} \frac{\partial}{\partial x_i} \left(\varepsilon_{sh} \kappa_{sh} \frac{\partial T_s}{\partial x_i} \right) + \alpha \left(T_f - T_s \right) + \widehat{\Gamma}_{ws} + S_f \tag{9}$$

Some Constitutive Equations

- Drag

$$
\beta = \begin{cases}
150\dfrac{\varepsilon_s^2 \mu_g}{\left(1-\varepsilon_s\right) d_s^2} + \dfrac{7}{4}\dfrac{\varepsilon_s \rho_g \left|v_g - v_s\right|}{d_s} & \text{if} \quad \varepsilon_s > 0.225 \\[2ex]
\dfrac{3}{4} C_D \dfrac{\left(1-\varepsilon_s\right)\varepsilon_s \rho_g \left|v_g - v_s\right|}{d_s}\left(1-\varepsilon_s\right)^{-2.65} & \text{if} \quad \varepsilon_s \leq 0.175 \\[2ex]
20\left(0.225-\varepsilon_s\right)\left[150\dfrac{\varepsilon_s^2 \mu_g}{\left(1-\varepsilon_s\right) d_s^2} + \right. \\
\left. \dfrac{7}{4}\dfrac{\varepsilon_s \rho_g \left|v_g - v_s\right|}{d_s}\right] + 15\left(\varepsilon_s - 0.175\right) \times \\
C_D \dfrac{\varepsilon_s \rho_g \left|v_g - v_s\right|}{d_s}\left(1-\varepsilon_s\right)^{-1.65} & \text{if} \quad 0.175 < \varepsilon_s \leq 0.225
\end{cases}
$$

- Interphase Heat Transfer

$$Nu = \frac{h_{fs} d_s}{\kappa_f} = \left(7 - 10\varepsilon_f + 5\varepsilon_f^2\right)\left(1 + 0.7 Re_p^{1/5} Pr^{1/3}\right) + \left(1.33 - 2.4\varepsilon_f + 1.2\varepsilon_f^2\right) Re_p^{0.7} Pr^{1/3} \quad (10)$$

- Thermal Conductivities

$$\kappa_f^* = \varepsilon_f \kappa_f = \left(1 - \sqrt{1 - \varepsilon_f}\right) \kappa_{gas} \quad (11)$$

$$\kappa_s^* = \varepsilon_s \kappa_s = \varepsilon_s \rho_s C_s d_s \frac{\sqrt{\pi \Theta}}{32 g_0} \quad (12)$$

where g_0 is the radial distribution function, defined in [?] as:

$$g_0 = \left[1 - \left(\frac{\varepsilon_s}{\varepsilon_s^{mp}} \right)^{\frac{1}{3}} \right]^{-1} \tag{13}$$

$$g_0 = \left[1 - \left(\frac{\sum_{h=1}^{3} \upsilon_{s,h}}{\varepsilon_{s,h}^{mp}} \right)^{\frac{1}{3}} \right]^{-1} \tag{14}$$

where $\upsilon_{s,h}$ is the corrected volume fraction of component *h* calculated

as

$$v_{s,h} = \frac{\varepsilon_{s,h}\Psi_h\varepsilon_s}{\sum_{h=1}^{3}\varepsilon_{s,h}} \tag{15}$$

Ψ is defined in Section **??** and $\varepsilon_{s,h}^{mp}$ is the maximum packing of the *h*-powder

- Density: Specific EOS for the fluid and solid phases

FETCH

- Finite Element Transient Criticality (FETCH) - which models criticality transients in spatial and temporal detail from fundamental principles, as far as is currently possible.

- The neutronics model in FETCH solves the neutron transport in full phase space with a spherical harmonics angle of travel representation, multi-group in neutron energy, Crank-Nicolson based in time stepping, and finite elements in space.

- The fluids representation coupled with the neutronics model is a TFGTM.

- The coupled models embodied in FETCH has already been validated against transient criticality experiments in multi-phase solutions.

- FETCH = Interface Module

- GEN IV and KNOO

Some Applications

- BNFL TDN Reactors - Dense Flows
- Risers - Dilute Flows
- The conceptual Nuclear Fluidized Bed Reactors